Local Differences of Pressure Near an Obstacle in Oscillating Water.

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[Plates 4 and 5.]

In a former paper* I showed that when a barrier fits tightly against the sides and across the bottom of a vessel of oscillating water (1) a vortex forms against each side of the barrier in turn as it becomes the lee side; (2) this vortex never forms while the water is attaining to the mean level, but only while it is falling below and rising above that level.

I suggested that such vortices were due to the conjunction of the main stream flowing over the barrier with opposing local streams created by local differences of pressure set up in the neighbourhood of the barrier by the oscillating water. Exception was taken to this explanation, and also, later, to experiments made with a box partially covered with thin gutta percha diaphragms, for the purpose of proving the formation of the local differences of pressure alluded to. The object of the present paper is to give an account of further experiments carried out for this same purpose, with pressure indicators which are free from the objection urged against the diaphragms, viz.: that they themselves might cause variations in the distribution of pressure.

Pressure Indicators.

Fig. 1 shows the form of pressure indicator I now employ, magnified. AB is a glass tube of inner diameter about $\frac{1}{8}$ inch and length about $\frac{5}{8}$ inch, in which a cork C is fitted, holding a very small glass tube D, through which a stem of graphite passes, carrying two small cork heads E and F. The stem and heads of the plunger EF are so proportioned that the whole either just floats or just fails to float in water, which ensures its moving to and fro through the carrier tube D with the least possible friction, when the whole pressure indicator is in position in the submerged obstacle. Since D is so small that no current can pass through it, any movement of the submerged

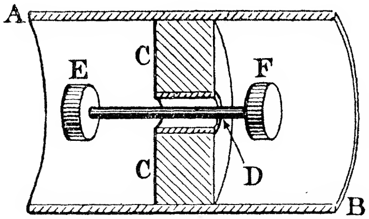

Fig. 1.—Pressure Indicator, Magnified.

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* "The Origin and Growth of Ripple-mark," 'Roy. Soc. Proc.,' A, vol. 84, pp. 290, 291 (1910).

plunger in the direction FE must indicate a greater pressure on F than on E, and in the contrary direction a greater pressure on E than on F.

Method of Using Pressure Indicators.

With these pressure indicators the various differences of pressure set up in oscillating water can be explored, but I shall here confine myself to those which arise close to a submerged obstacle.

In my former paper* each half oscillation, or swing of the water in one direction, was called a swing. The time during which the water approaches the mean level position was called the first part of the swing, and that during which it departs from the level was called the second part of the swing. Using the same terms, the suggestions made on pp. 292–294 as to the differences of pressure set up by the presence of an obstacle in oscillating water may be thus expressed:

(1) During the first part of any swing the pressure at any point in the lee of a submerged obstacle is less than the pressure at any point—however near it—on its summit.

(2) During the second part of any swing the above applies still to the upper portion of the lee side, but over the lower portion the case is reversed, and the pressure at any point there is *greater* than the pressure at any point on the summit of the obstacle.

Construction of the Obstacle.

In proving these conclusions by means of pressure indicators, the obstacle used is a block of wood with vertical sides, padded at the ends and underneath to enable it to be pressed tightly against the sides and bottom of the tank, and hollowed out in the part where the pressure indicators are placed. Fig. 2 shows a vertical section in perspective of the hollow portion of the block and of the pressure indicators, EF, which are held in position by tightly fitting bored corks, H, K. The circular hole M, about $\frac{1}{16}$ inch in diameter, is the sole means of communication between the water in the cavity and that outside. Through this hole the pressure of the water passing over the obstacle can be communicated to E_1, E_2, the inner heads of the plungers of the pressure indicators, but no oscillation can be set up in the cavity through so small a hole, and only the very small quantity of water that is displaced by the graphite rods in their movements to and fro passes in and out. Great care has to be taken to rid the obstacle and pressure indicators of all air before they are placed in position, as the smallest air bubble in one of the glass tubes may impede the motion of the plunger. At first the pressure indicators were completely enclosed in the obstacle, all except the outer edges of their tubes, which were flush with its right-hand side, instead of protruding as in fig. 2. Short lengths of horsehair driven into the heads F_1, F_2 (fig. 2), parallel to the axes of the tubes, then enabled the movements of the plungers to be observed. As, however, it was found that exactly the same results were obtained when the tubes protruded a quarter of an inch or so beyond the obstacle, the more convenient method shown in fig. 2 was adopted.

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* *Loc. cit.*, pp. 287, 292.

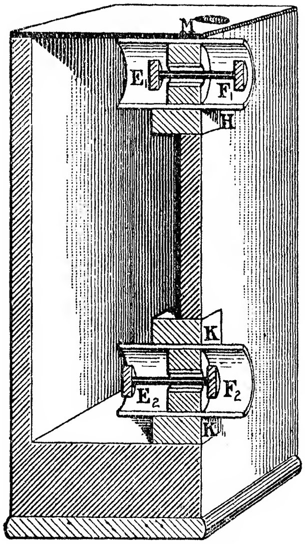

Fig. 2.—Section in Perspective of Obstacle fitted with Pressure Indicators.

The meaning of any movements of the plungers, when the water is oscillated, is quite clear. The only variable pressures acting on the plungers are the pressure at M, transmitted through the water in the cavity to E_1, E_2, and the pressures at F_1, F_2. If both plungers are pressed outwards it shows that the pressure is greater at M than that either at F_1 or at F_2; if both are pressed in, the reverse is the case. If one is in and the other out, the pressure at M is less than the external pressure on the first and greater than that on the second.

Fig. 3 (Plate 4) is a photograph of the obstacle with the pressure indicators in position and the water at rest. The obstacle was well to the left of the middle of the trough, the ends of which, as well as the surface of the water, are out of the picture. In order that the direction of flow of the water at various points might be recorded, the three stream indicators made of ravelled silk tipped with cork were used. The one over the obstacle was mounted on a very long headless pin so as to keep it well away from the local disturbances near the obstacle. The one on the floor of the trough close to the obstacle was to the right of the tubular indicator, and the further one was in a line with it. The hole of communication with the cavity marked M in fig. 2 can be seen slightly to the right of the upper tubular indicator. As the indicators are placed, they are evidently in the lee of the obstacle during a swing of the water from left to right, and on its weather side during one from right to left.

Local Differences of Pressure as Shown by Pressure Indicators.

Figs. 4, 5, and 6 are instantaneous photographs taken while the water was being oscillated—fig. 4 during the first part of a swing from left to right, fig. 5 during the second part of one in the same direction, and fig. 6 while the water swung from right to left.

The stream indicators in fig. 4 show that during this first part of a swing the whole of the water was moving from left to right—that close to the lee side of the obstacle as well as that over it and that at some distance away. The plungers of the pressure indicators are both pushed out as far as they will go, showing that the pressure at each of the points F_1, F_2 (fig. 2), on the lee side of the obstacle was less than that at the point M on top. This is entirely in accordance with the first suggestion made in my former paper and restated on p. 406.

Fig. 5 was taken during the second part of a swing from left to right. The distribution of pressure formerly suggested, and given again on p. 406, is here also justified. For while the upper plunger still remains fully out, the lower is pressed home, showing that during the second part of a swing, although the pressure on the upper part of the lee side of the obstacle remains less than that on top, the pressure on its lower part is greater than that on top. Not only this, however, but the stream indicators point to the fact that while the main stream continued to flow from left to right, there was a current in the opposite direction close to the obstacle ; for the stream indicator close to the block has a distinct trend from right to left, although the other two are bent right down in the opposite direction. Here, then, is evidence, not only of the suggested differences of pressure, but also of the fact that the change in the direction of pressure on the lower part of the lee side is the result of no general turning movement on the part of the lower water, but is purely local, and is due to the presence of the obstacle.

Fig. 6 was taken in the course of a swing of the water from right to left, and shows, as was to be expected, that the pressure at any point on the weather side of an obstacle is greater than that at a point on top.

To return to the conditions in the lee of the obstacle. In my paper on "The Origin and Growth of Ripple-mark" I remarked, "the second condition for the formation of a ripple vortex is that the resultant gravity pressure along the ridge on its lee side shall tend upwards."* With the obstacle having perfectly vertical sides with which the above experiments were made, there was, of course, no vertical component in the pressure of the water on the sides, but the direction of the vertical component of the pressure of the water close to the side was easily tested by another experiment. I embedded a pressure indicator in a solid obstacle as shown in section in fig. 7, and, in order to have a perfectly fair test, I used sometimes a plunger having a slightly greater specific gravity than water and sometimes one with less. The result was the same in each case, and was such as was to be expected from the experiments with horizontal indicators—during the first part of a swing from left to right the plunger was pressed downwards, during the second part it was raised. It is clear that these local differences of pressure, in water that would otherwise be at rest in the lee of a barrier, must cause local currents there—downwards during the first part of a swing and upwards during the second. During the first part of a swing, therefore, there is a local pressure difference which creates the condition necessary to give rise to such jets as I have observed by placing a grain of permanganate of potash on the summit of an obstacle.* During the second part of the swing the pressure indicators show that there must be a local current in the lee of the obstacle, somewhere below the surface, which moves in opposition to the main stream *towards* the obstacle and *upwards*. Two currents opposing one another in this way are all that is needed to cause such a vortex as was made manifest in the lee of the obstacle by the grain of permanganate of potash* during the second part of the swing.

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* *Loc. cit.*, p. 294.

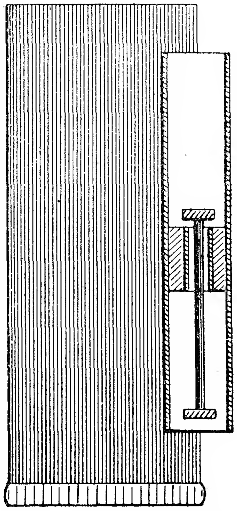

Fig. 7.—Obstacle with Vertical Pressure Indicator for Testing Vertical Pressure.

Conclusion.

I submit, therefore, that these pressure indicators afford conclusive proof of the truth of the following suggestions, that I first made in 1904, in explanation of the jet and vortex that I had observed in the lee of a submerged obstacle under oscillating water:—

1. When the water is approaching the mean level there is a diminution of pressure, or partial vacuum, created in the lee of the obstacle. (Proof in fig. 4.)

2. When the water is departing from the mean level the diminution of pressure continues high up on the lee side, but over the lower part there is a pressure in the opposite direction to that of the main stream. (Proof in fig. 5.)

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* *Loc. cit.*, p. 294.

3. The jet in the first part of a swing is due to the local current created by the local difference of pressure; the vortex in the second part of the swing is due to the conjunction of the main stream with the opposing local current set up by the local pressure difference.

My warm thanks are due to Mr. MacKinney for the zeal and ability he displayed in taking the instantaneous photographs from which figs. 3–6 are reproduced.

DESCRIPTION OF PLATES.

Fig. 3.—Obstacle with Pressure and Stream Indicators in Position in Tank, with the Water at rest.
Fig. 4.—Swing from Left to Right—First Part.
Fig. 5.—Swing from Left to Right—Second Part.
Fig. 6.—Swing from Right to Left.

Some Problems Illustrating the Forms of Nebulæ.

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The possible forms of distribution of a mass of gaseous material under the influence of its own gravitation are of considerable interest in the nebular theory. The law of density which it appears most reasonable to assume is Boyle's Law, in which the pressure is proportional to the density, unless the pressure becomes so great that the material begins to resemble an incompressible substance. Although it is unlikely that the temperature is uniform throughout, still the solution under this restriction would be of value as a step in the direction of greater knowledge as regards possibilities in astronomical phenomena.

The equations can be formed and lead to a differential equation for the surfaces of equal density. This equation is not linear, and in the three-dimensional case little progress to a general solution has been made. In the two-dimensional case, however, considerable progress can be made.

A number of years ago I obtained the exact solution of the statical case of symmetry about the origin. Shortly after I found that Pockels had obtained the complete solution of the statical two-dimensional equation, and